Contrasting biogeography of endemic and alien terrestrial species in the Canary Islands

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Abstract

Endemics and alien organisms can be considered two faces of the same coin, since management of both groups of taxa have strongly interrelated conservation implications. Islands are rich in endemic species and are also very vulnerable to biological invasions. We analysed the biogeography and taxonomy of endemic and alien terrestrial species in the Canary Islands including fungi, lichens, bryophytes, vascular plants, arthropods, molluscs, annelids and vertebrates. By using the plant dataset we also tested the hypothesis that there is less taxonomic similarity between aliens and natives than between endemics and non-endemic natives. Although in the Canary Islands species richness of endemic species (28% of terrestrial flora and fauna) was higher than for alien species (3%), this trend was very much dependent on taxa and island. For example, more than half the annelids present in the islands are alien, and the flora of Fuerteventura has almost as many endemics as alien species. As hypothesized, for plants, there were more exclusively alien families (34) than families with only endemic species (5). Moreover, neither alien nor endemic plant species represented a random assemblage of taxa: most families with aliens were over-represented compared to the taxonomy patterns of the native flora, while for endemics almost the same proportion of families was over- and sub-represented compared to proportions of non-endemic natives.

Keywords: biological invasions, biotic homogenization, non-native plants and animals, taxonomic similarity.

Resumen. *Contraste biogeográfico de las especies terrestres endémicas y exóticas de las Islas Canarias*

Los organismos endémicos y exóticos forman parte de las dos caras de una misma moneda puesto que la conservación de ambos grupos posee implicaciones para la conservación que están fuertemente interrelacionadas. Las islas son ricas en especies endémicas y también muy vulnerables a las invasiones por especies exóticas. Hemos analizado la biogeografía y la taxonomía de las especies terrestres endémicas y exóticas de las islas Canarias que incluyen hongos, líquenes, briófitos, plantas vasculares, artrópodos, moluscos, anélidos y vertebrados. Utilizando la base de datos para plantas también hemos testado la hipótesis de que existe una menor similitud taxonómica entre especies exóticas y nativas que entre endémicas y nativas no endémicas. A pesar de que en las Islas Canarias la riqueza y densidad de especies endémicas (28% de la flora y fauna) es mayor que la de las especies exóticas (3%), esta tendencia depende del grupo de organismos y de la isla considerada. Por ejemplo, más de la mitad de los anélidos presentes en las islas son exóticos o la flora de Fuerteventura posee tantas especies endémicas como exóticas. El análisis confirma la hipótesis de que en la flora canaria hay más familias de especies vegetales que exclusivamente poseen especies exóticas (34) que familias con sólo especies endémicas (5). Además, ni las especies vegetales exóticas ni endémicas constituyen una representación al azar de la taxonomía de la flora: la mayor parte de especies exóticas se encuentran sobre-representadas en ciertas familias. No obstante, las especies endémicas se encuentran sobre o sub-representadas en ciertas familias en comparación con las especies nativas no endémicas.

Palabras clave: invasiones biológicas, homogeneización biótica, plantas y animales no nativos, semejanza taxonómica.

Introduction

In recent years there has been a major research focus on the ecology and evolution of island species. Islands have a disharmonic flora and fauna, and a lower species diversity compared to “source” and homologous mainland areas (Bramwell, 1979). Insular systems are major plant endemic species centres in positive relationship to their size and isolation. The best examples are found in big isolated islands such as Madagascar with 12000 species 80% of which are endemic or New Zealand with 82% endemic species (Lean & Hinrichsen, 1990). Endemic plant species are also common in small islands such as Mauricio Island —280—, the Madeira Islands —129— (Lean & Hinrichsen, 1990); Corsica —240— (Médail & Verlaque, 1997) or the Balearic Islands —89— (Vilà & Muñoz, 1999).

This biological simplicity along with the perseverance of anthropogenic disturbances to which islands are subjected, make islands very vulnerable to ecological changes like biological invasions by alien species (Atkinson & Cameron, 1993; D’Antonio & Dudley, 1995; Eliasson, 1995; Loope et al., 1989; McDonald & Cooper, 1995). The percentage of alien plant species is very high in islands (Lonsdale, 1999). For example: Hawaii —44%—, New Zealand —40%—, British Islands —43%—, Ascension Island —83%— (Vitousek et al., 1997).

In the last decade there has been growing emphasis on experimental research about the ecological processes that limit endemic and alien populations (e.g. Gaston, 1994; Drake et al., 1989, respectively). However, these studies have mostly been carried out in isolation of each other, even though conservation of endemic species and control of alien species are two worldwide management goals that often require complementary approaches (Usher, 1986; Schierenbeck, 1995). At the regional scale comparative studies of the alien and endemic taxa component can provide substantial new insights to our understanding of the general patterns of biological invasions as well as the dynamics of threatened species (Cowling & Hilton-Taylor, 1997; McIntyre, 1992). It also could aid in planning management practices to control aliens and to protect endemics.

For example, there is a general notion that introduced species are expanding and contributing to the homogenization of flora and fauna worldwide (Hobbs & Mooney, 2000; Lockwood & McKinney, 2001). Conversely, endemic species tend to be rare in terms of abundance and frequency distribution; and are threatened by environmental, stochastic and human activities (Kruckeberg & Rabinowitz, 1985) making them more vulnerable to contraction and extinction (Lockwood & McKinney, 2001). However, despite some well known introduced species being extremely invasive and harmful in very distinct ecosystems and regions, most naturalized species present in regional floras and faunas are rare because their local and regional abundance is low (Lloret et al., 2004; Vilà & Muñoz, 1999). Correspondingly, the concept of endemism is often confused with that of rarity but they are not synonyms. For instance, some endemic plants are dominant species in very common type communities.

We selected the Canary Islands as the study region due to its high biodiversity and endemism (La Roche & Rodríguez, 1994; Santos, 1990) to address the following questions: (1) What is the alien and endemic proportion of terrestrial flora and fauna in the Canary Islands? 2) Specifically for plants: Are there taxonomic similarities between the alien and the native flora?, and 3) Are endemic plants a random selection of native plant families?

Material and methods

A database with fungi, lichens, bryophytes, vascular plants, arthropods, molluscs, annelids and vertebrates representing both endemic species and alien naturalized species of the Canary Islands was constructed according to the BIOTA project databank (Izquierdo et al., 2001). We chose this source because it is the most complete and updated biodiversity listing of this region. Izquierdo et al. (2001) compilation is based on the review of bibliographic references supervised by more than 50 taxonomic experts. Nevertheless, we are aware that the compilation is not based on current field work and therefore, some taxa might not be updated. Still, screening a single bibliographic source guaranties homogeneity in nomenclature and taxonomic treatment between endemics and aliens. Furthermore, this approach minimizes the different treatments alien species receive in different checklists (Pysek et al., 2004). The nomenclature follows Hawksworth et al. (1996) for fungi, Corley et al. (1981) for bryophytes, Strasburger & Sitte (2004) and Salvo Tierra (1990) for vascular plants, Bank et al. (2002) for molluscs, De la Fuente (1994) for arthropods, Pleguezuelos et al. (2002) for amphibians and reptiles, Hoyo et al. (1992-1999) for birds, and finally Corbert & Hill (1991) for mammals.

For each island and group of taxa we calculated 1) the richness of endemic and alien species as the absolute number of endemic and alien species respectively and the percentage of endemic and alien species from the total. Alien plants were also classified by their region of origin according to Sanz-Elorza (2004).

To test whether endemic plants were taxonomically random assemblages, overrepresentation of main endemic families was assessed by comparing the ratio Pen = (endemic species within a family/total number of endemic species) with the ratio Pnn= (native non-endemic species within a family/total number of native non-endemic species) with a X^2 test (Cowling & Hilton-Taylor 1997). Likewise, overrepresentation of main alien plant families was assessed by comparing the ratio Pal = (alien species within a family/total number of alien species) with the ratio Pn = (native species within a family/total number of native species).

Differences in over- and sub-representation of endemic and alien plant species taking into account phylogenetic constraints, that is, pairing those families that have both endemic and alien representatives, was examined by counting the proportion of pairs in which only endemics or only aliens were over- or sub-represented.

Taxonomic similarity between endemic and non-endemic native plants and between alien and native plants was compared by a three step method: 1) as the number of families with only endemic or alien species respectively, 2) the proportion of families with an over- or sub-represented number of endemic or alien species and finally, 3) the proportion of families with an over- or sub-represented number of endemic or alien species taking into account the families containing both alien and endemic species.

Results

In total, the terrestrial flora and fauna of the Canary Islands have 3572 (28%) endemic and 339 (3%) alien species. There is not a relationship between island area and the number of endemic and alien species (Spearman: rho = 0.29, p = 0.48 for endemics; rho = 0.61, p = 0.14 for aliens) nor with distance to the coast (Spearman: rho = 0.32, p = 0.43 for endemics; rho = 0.07, p = 0.86 for aliens). Tenerife and Gran Canaria are the islands with the highest density of endemic and alien species (Table 1). These islands also harbour the highest percentage of aliens but not of endemics. The latter reach the highest percentage in El Hierro and La Gomera. There is a positive correlation between the number of alien and the number of endemic species (Spearman: rho = 0.86, p = 0.04).

The groups with the highest number of endemic species are arthropods with 2764 (41.06%) species followed by vascular plants 511 (29.35%). For aliens, the highest number of alien species is also found in vascular plants and arthropods representing a total of 249 (12.48%) and 109 species (1.59%), respectively. There are not endemic annelids in any island but 18 alien species. In contrast, there are no alien molluscs, bryophytes, fungi and lichens species in any island, but these taxa have endemic representatives: 192 gastropods, 10 bryophytes, 107 fungi and 26 lichens. The number of alien vertebrate species is higher than endemic species in all islands except in El Hierro (Fig. 1).

The 511 endemic vascular plant species are distributed in 59 families, 2 of which have only endemic species (Table 2). Families with endemics have on average 9.02 ± 2.79 species per family. The families with more endemic species are Asteraceae

Table 1. Geographical characteristics of the Canary Islands.

Island	Area (km^2)	Distance to mainland (km)	Age (Myr)	Maximum altitude (m)
El Hierro	268	376	0.8	1520
Fuerteventura	1657	98	21	807
Gran Canaria	1558	196	14	1950
La Gomera	368	320	12.5	1484
La Palma	707	402	2	2423
Lanzarote	845	116	15.5	670
Tenerife	2033	288	12	3714

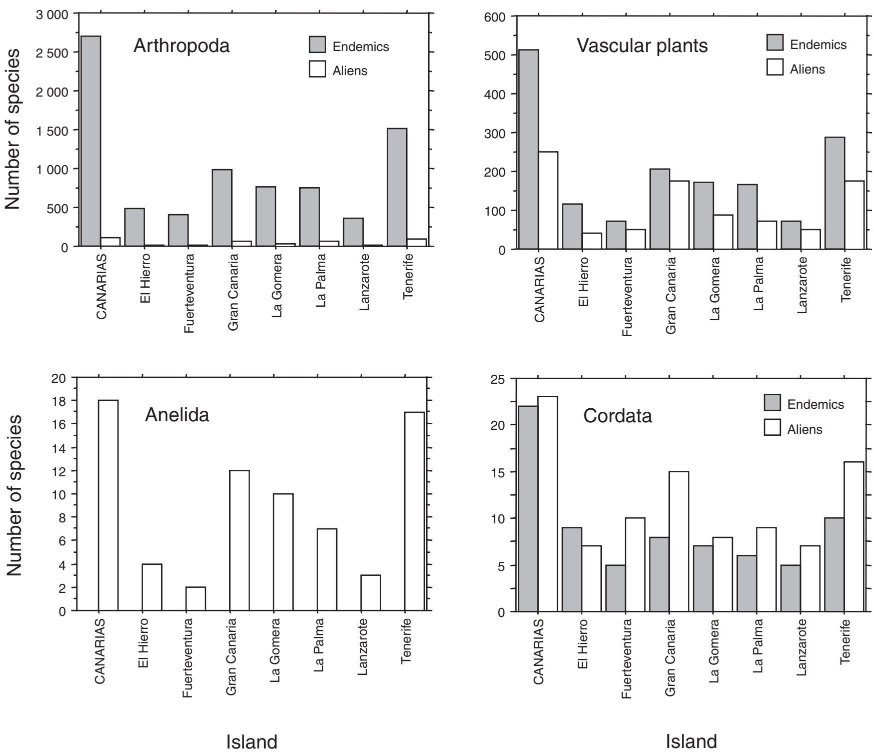

Figure 1. Number of endemic and alien arthropoda, vascular plants, annelia and cordata in the Canary islands.

(141), Lamiaceae (49), Fabaceae (46) and Crassulaceae (34). There are as many sub-represented (18.87%) as over-represented (18.52%) families (Table 2).

Although in total there are twice as many endemic plants as alien plants, in some islands such as in Fuerteventura and Lanzarote, richness of alien plants is only 31.50% and 29.57% lower than endemic plants. In Gran Canaria, this value is only 14.63% (Fig. 1).

Most alien plants have an American origin (44.84%) followed by African (18.39%), European (15.70%) and Asian (14.80%). Many species have a Mediterranean origin: more than half of the European and African species belong to the Mediterranean basin and South Africa, respectively. The least represented region of origin is Oceania (6.28%).

Alien plants belong to 80 families, 34 of which are totally alien (Table 3). As for endemics, the distribution of species among families is strongly skewed with most families having only one alien species. The number of species per family (3.01 ± 0.38) was significantly lower than for endemics (t-value = 2.53, p = 0.012). This trend was also found when we accounted for phylogenetic identity (paired t-value = 2.11, p = 0.012). Only Araceae, Asclepiadaceae, Cucurbitaceae, Chenopodiaceae, Malvaceae, Oleaceae and Solanaceae had a few more alien than endemic species. The families with more alien species are Asteraceae (19), Caesalpiniaceae (11), Crassulaceae (9), Cactaceae (9), Mimosaceae (8) and Aizoaceae (8). Most species are over-represented among families (51.16%) while sub-represented families represent only 25.58% of the families in which native species are also present.

Overall, alien plant species are less similar to native species than endemic species are because 1) there are more alien than endemic families, 2) over- and sub-representation of plant species within families is higher for alien species (76.74%) than for endemics (37.74%) (X^2 = 4.56, p = 0.03) even when only the families containing both aliens and endemics are considered (81.48% for aliens and 48.15% for endemics, X^2 = 6.58, p = 0.01), and finally 3) when pairing endemic and aliens within the same family, there were 4 pairs which followed the same representation trend, 2 pairs in which only endemics differed in representation, 12 pairs in which only aliens differed in representation and 5 pairs in which both groups of species differed but in opposite directions. Therefore, even when we take into account phylogenetic constraints, alien plant species are taxonomically less similar to native species than endemic species are.

Discussion

In the Canary Islands species richness and density of endemic species is higher than for alien species. However, this trend is very much dependent on species and island. For example, in most islands there are more alien vertebrate species than endemic vertebrates and more than 50% of the annelids are alien with no endemic representatives. The representation of alien species is much lower than the values found for other oceanic islands (MacDonald & Cooper, 1995; Vitousek et al*.,* 1997).

There is no relationship of alien and endemic richness with island size or distance to the coast as predicted by classical biogeographic theory (McArthur & Wil-

Table 2. Number of endemic vascular plant species per family in the Canary Islands. The number of endemic species in the families containing also non-endemic native species is followed with a sign showing the comparison with the contribution of the native species to the family: + overrepresented as endemic species, – underrepresented as endemic species. We have not listed the families Acanthaceae, Arecaceae and Pinaceae which also have alien species but any native non-endemic species (see Table 3).

Families with only endemic species		**Families with endemic and non-endemic species**			
Araliaceae	2	Amaranthaceae	1 –	Hyacinthaceae	2
Cneoraceae	1	Amaryllidaceae	1	Hypericaceae	2
		Apiaceae	15	Juncaceae	1 –
		Araceae	1	Lamiaceae	49 +
		Asclepiadaceae	2 +	Liliaceae	1
		Asteraceae	141 +	Malvaceae	2
		Boraginaceae	24 +	Myricaceae	1
		Brassicaceae	27	Myrsinaceae	1
		Campanulaceae	2	Oleaceae	1
		Caryophyllaceae	22	Orchidaceae	3
		Celastraceae	1	Orobanchaceae	2 –
		Chenopodiaceae	3 –	Plantaginaceae	2
		Cistaceae	12 +	Plumbaginaceae	13 +
		Convallariaceae	4	Poaceae	8 –
		Convolvulaceae	10 +	Polygonaceae	1
		Crassulaceae	34 +	Resedaceae	2
		Cucurbitaceae	1	Rhamnaceae	2
		Cyperaceae	2 –	Rosaceae	7
		Dipsacaceae	4 +	Rubiaceae	2 –
		Dracaenaceae	1	Rutaceae	3
		Ericaceae	2	Sambucaceae	2
		Euphorbiaceae	9 –	Santalaceae	4 +
		Fabaceae	46	Scrophulariaceae	10
		Frankeniaceae	1	Solanaceae	3 –
		Fumariaceae	1 –	Urticaceae	4
		Gentianaceae	1	Violaceae	3
		Globulariaceae	2		

Table 3. Number of alien vascular plant species per family in the Canary Islands. The number of alien species in the families also containing native species is followed with a sign showing the comparison with the contribution of the native species to the family: + overrepresented as alien species, — underrepresented as alien species.

Families with only alien species		Families with alien and native species			
Aceraceae	2	Acanthaceae	1 +	Papaveraceae	2
Agavaceae	5	Aizoaceae	8 +	Pinaceae	3 +
Alstroemeriaceae	1	Alliaceae	2	Plumbaginaceae	2 –
Balsaminaceae	2	Amaranthaceae	1 +	Poaceae	7 –
Basellaceae	1	Amaryllidaceae	1 +	Ranunculaceae	2
Bignoniaceae	3	Anacardiaceae	1 +	Rosaceae	3
Cactaceae	9	Apiaceae	3 –	Rubiaceae	1 –
Cannaceae	1	Apocynaceae	1 +	Salicaceae	2 +
Capparaceae	1	Araceae	3 +	Scrophulariaceae	3 –
Caprifoliaceae	3	Arecaceae	1 +	Solanaceae	20 +
Casuarinaceae	2	Asclepiadaceae	4 +	Valerianaceae	1
Commelinaceae	6	Asphodelaceae	3 +	Verbenaceae	1 +
Hydrangeaceae	1	Asteraceae	19 –		
Hydrophyllaceae	1	Brassicaceae	4 –		
Meliaceae	1	Caesalpiniaceae	11 +		
Mimosaceae	8	Chenopodiaceae	4		
Musaceae	1	Cistaceae	3		
Myoporaceae	2	Convolvulaceae	7 +		
Myrtaceae	3	Crassulaceae	9		
Nyctaginaceae	3	Cucurbitaceae	2 +		
Passifloraceae	1	Dracaenaceae	1 +		
Phormiaceae	1	Ericaceae	1 +		
Phytolaccaceae	1	Euphorbiaceae	2 –		
Pittosporaceae	1	Fabaceae	5 –		
Proteaceae	1	Geraniaceae	2 –		
Sapindaceae	1	Hyacinthaceae	1		
Simaroubaceae	1	Iridaceae	5 +		
Simmondsiaceae	1	Lamiaceae	4 –		
Sterculiaceae	1	Liliaceae	1 +		
Tiliaceae	1	Malvaceae	5 +		
Tropaeolaceae	1	Moraceae	2 +		
Ulmaceae	2	Oleaceae	2 +		
Vitaceae	2	Onagraceae	2		
Zingiberaceae	1	Oxalidaceae	2 +		

son, 1967) suggesting that species richness is more dependent on the ecological breadth of the island (e.g. geology, age, topography) than on dispersal constraints (Eliasson, 1995).

The analysis is consistent with the general trend that the endemic (Cowling & Hilton-Taylor, 1997; Prance & Elias, 1977) and the alien (Pysek, 1998) components of the flora are not random assemblages of species. However, our results for alien plants do not exactly match with the taxonomic patterns of plant invasions at the global scale (Pysek, 1998). At the global scale, Poaceae and Compositae are the three most over-represented families. However, in the Canary Islands, these families are some of the most sub-represented by aliens. On the contrary, Iridaceae and Aizoaceae are sub-represented at the global scale but in the Canary Islands they are over-represented by aliens. Noticeably, there are regional differences in the taxonomic patterns of plant invasion depending on differences in the deliberate and reiterated introductions of certain species, their origin and environmental characteristics of the receptive community (Lonsdale, 1999).

As hypothesized, several lines of evidence support lower taxonomic similarity between alien plants and natives than between endemic and non-endemic natives. As discussed above 1) there are more alien than endemic families, 2) the pool of alien species is less of a random selection of species than it is for endemics and 3) within a family there is more over- and sub-representation of alien plants than of endemics. Therefore, introduction followed by naturalization of alien species increases the taxonomic heterogeneity within the flora. Obviously, the causes underlying the regional taxonomy patterns of alien and endemic species are different. Endemism is the result of geological legacy, insularity and certainly the effects of global change on species conservation (Marrero, 2004). In contrast, the alien component depends mainly on the origin and selection of introduced species and the propagule pressure controlled directly or indirectly by humans (Lonsdale, 1999).

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